AD A030726

DEPARTMENT OF THE NAVY
DAVID TAYLOR MODEL BASIN

HYDROMECHANICS

AERODYNAMICS

STRUCTURAL MECHANICS

APPLIED MATHEMATICS

CALCULATED AND OBSERVED SPEEDS OF CAVITATION ABOUT TWO- AND THREE-DIMENSIONAL BODIES IN WATER

by

Hugh B. Freeman

APPROVED FOR public release;
distribution unlimited

November 1942

Report 495

1

6

CALCULATED AND OBSERVED SPEEDS OF CAVITATION ABOUT TWO- AND THREE-DIMENSIONAL BODIES IN WATER

by

10 Hugh B. Freeman

11 Nov[redacted]42

12 23 p.

14 DTMB ~~Report~~ 495

ACCESSION for

NTIS

104650

DISTRIBUTION STATEMENT A

Approved for public release;
Distribution Unlimited

A

THE DAVID TAYLOR MODEL BASIN

Rear Admiral H.S. Howard, USN
DIRECTOR

Captain H.E. Saunders, USN
TECHNICAL DIRECTOR

Commander W.P. Roop, USN
STRUCTURAL MECHANICS

Lt. Comdr. A.G. Mumma, USN
VARIABLE PRESSURE WATER TUNNELS

L.F. Hewins
PRINCIPAL NAVAL ARCHITECT

K.E. Schoenherr, Dr.Eng.
SENIOR NAVAL ARCHITECT

D.F. Windenburg, Ph.D.
SENIOR PHYSICIST

PERSONNEL

The tests were conducted in the 24-inch water tunnel by L. Rubinowitz. The formulas and characteristics of the TMB forms presented in Table 1 were developed by L. Landweber. The report was written by Hugh B. Freeman.

DIGEST

One of the major limitations on the useful speed of sound-projector domes is the noise created by the flow about the dome. There are two sources of such noise; cavitation and eddying.

When the pressure distribution about a body is known, the cavitation speed for any given submergence can be readily computed as the speed at which the minimum pressure becomes equal to the vapor pressure of water. Calculations of the pressure distributions about families of ellipsoids and elliptical cylinders and several miscellaneous cylinders and struts are made by means of the potential theory. Comparison of the cavitation speeds for these forms with the cavitation speeds calculated from experimental pressure distribution curves for certain symmetrical airfoils and airship forms produced the following results:

1. Bodies of revolution are greatly superior, as regards cavitation, to cylindrical bodies.

2. The elliptical shapes are much superior to the more highly streamlined forms for both two- and three-dimensional forms.

The elliptical form suffers from the disadvantages of high drag and poor eddying characteristics. For this reason, a family of shapes, known as the TMB forms, was designed, each consisting of an elliptical forebody and a streamlined tail, thereby combining the advantages of both forms. The generalized coordinates of these forms are given in Table 1 on page 7 of this report.

Nine models of various existing and proposed sound domes were tested in the 24-inch variable pressure water tunnel to determine their cavitation speeds. These included seven "necked" domes, namely, WEA-1, JK-9, British, RA78F208A, TMB-1, -3 and -4, and two strut-type domes, WEA-1 Strut and TMB-2. The TMB domes were all based on the TMB form previously mentioned. Outline drawings of the domes are shown in Figure 5 on pages 8 and 9, photographs of the various stages of cavitation are shown in Figures 7 to 15 on pages 11 to 15, and the major characteristics and the test results are listed in Table 2 on page 10. The main conclusions deduced from these tests may be summed up as follows:

1. Too short a neck causes interference between neck and body with consequent cavitation at the junction, as was shown by the results on TMB-1 and TMB-3. The minimum length of neck should be about one diameter of the body.

2. The length-thickness ratio of the neck must be much greater than the length-diameter ratio of the body. This is shown by the early cavitation on the necks of WEA-1 and JK-9 as compared to the body cavitation, and is in agreement with the previously noted theoretical conclusion on the superiority of three-dimensional over two-dimensional forms.

3. The TMB forms are distinctly superior as regards cavitation to any of the other forms for like length-thickness or length-diameter ratios.

4. The strut forms cavitate at higher speeds than indicated by the calculations, because the flow is more nearly three- than two-dimensional owing to the short length of the struts.

Confirmation of these results is obtained by comparison with previous tests of 12 strut forms in the NACA high-speed basin, see reference (5) on page 18 of this report. The three struts which gave the highest cavitation speeds are very similar to the TMB form.

The test data on the British dome and the calculations on the old type of spherical dome indicate that the cavitation speeds are considerably higher than the limiting service speeds in both cases. The causes of failure of these domes is probably noise due to excessive eddying flow known to exist about bodies of low length-diameter ratio.

Observations of the flow separation on the British and TMB-1 forms were made during the water-tunnel tests by streamers mounted on the form. Separation occurred much farther aft on the TMB-1 form, so that the area of violent eddying flow is much smaller and also farther from the sound projector than on the British form. The TMB form therefore offers the possibility of considerable reduction of eddying noise in addition to reduction of cavitation noise.

CALCULATED AND OBSERVED SPEEDS OF CAVITATION ABOUT TWO- AND THREE-DIMENSIONAL BODIES IN WATER

ABSTRACT

The computed cavitation speeds for a wide variety of two- and three-dimensional body forms are presented, together with the observed cavitation speeds of nine model sound-projector domes tested in the 24-inch variable pressure water tunnel of the David W. Taylor Model Basin.

One of the most interesting and important findings of the theoretical investigation is the fact that an elliptical shape for either a two- or a three-dimensional body has the highest cavitation speed of all the shapes calculated. Conventional streamlined forms have relatively low cavitation speeds.

A body form was developed at the Taylor Model Basin designed to utilize the high cavitation speed of the ellipse and to retain the low drag characteristics of the streamlined form. Models based on this form gave the highest cavitation speeds of any observed in the test program. Cavitation on sound-projector domes may be avoided, throughout the speed range of the fastest vessels, by the proper choice of form and length-diameter ratio.

INTRODUCTION

Underwater listening devices and sound projectors used by naval vessels in locating the position of an enemy ship or submarine are limited in their useful speed range by the existence of reverberation effects in the water, by the background noises generated by the hull of the ship passing through the water, by the ship's own propeller noises and by the noises set up in the flow about the bodies in which the sound devices are housed. Only the background noises set up about the sound domes themselves are discussed in this report. These are of major importance because of the fact that the origin of the noises is in such close proximity to the sound receiver. The early type of spherical dome, in use in the United States Navy, could be used effectively only at speeds below 15 knots and was entirely useless at speeds above 18 knots. The improved type of streamlined dome developed in England increased the useful speed range to about 20 to 24 knots. Above this speed the signals were obscured by the water noises about the sound domes, and by the ship and propeller noises.

There are two known sources of water noises arising about a body moving through a fluid. These are cavitation and eddying. Although the importance of cavitation noise has long been recognized, very little information exists as to the speeds at which it may be expected to occur about bodies of different form. Even less is known about eddying or vortex noises, i.e., noises arising from the separation of the flow from the after portion of the body and the resulting violent eddying or "burbling." Vortex noises have been measured, however, in aerodynamic research (1).* Because of the similarity of flow in water and in air it may be concluded that the

* Numbers in parentheses indicate references on page 18 of this report.

vortex noises may be of importance in the flow of water about sound domes. Later in this report it will be shown that some of the existing sound-projector domes become ineffective before the cavitation speeds of the domes have been reached, and it follows that the noises responsible for their failure probably arise from some source other than cavitation.

COMPUTED CAVITATION SPEEDS

The speed at which cavitation should occur about any shape of body may be computed provided the pressure distribution about the body is known. Cavitation is known to occur when the pressure in the flow is reduced to the vapor pressure of the liquid. For all practical purposes this may be considered the point at which the pressure in the flow becomes absolute zero. For sea water, the error due to this assumption is small because of the small magnitude of the vapor pressure.

From Bernoulli's equation it may be shown that the speed for cavitation (2),

$$V_c = \sqrt{\frac{2gh}{\left(\frac{P}{q}\right)_{\min}}}$$

where g is the acceleration of gravity

h is the head of water in feet, absolute

$(P/q)_{\min}$ is the value of ratio of the minimum pressure about the body to the dynamic pressure in the stream, disregarding the negative sign

$q = \frac{1}{2}\rho V^2$, where ρ is the mass density in slugs per cubic foot and V is the velocity in feet per second.

The pressure distributions about bodies of various shapes may be computed from the potential theory of flow. The minimum pressures about a family of ellipsoids and about a family of elliptical cylinders may be computed by the method of Zahm (3). Pressures about a family of struts and other miscellaneous cylinders may be computed by the method of Theodorsen (4). The cavitation speeds for Joukowski symmetrical airfoils and for airship forms may be computed from experimental curves of pressure distribution.

After these calculations had been made for the bodies to which the methods applied, the cavitation speeds were computed, for the minimum pressures yielded by these calculations, by means of the equation given previously.

The cross sections of the bodies investigated are shown in Figure 1, page 3, and the cavitation speeds are plotted in Figure 2, page 5, against the length-diameter and the length-thickness ratios, respectively, for the bodies of revolution and for the cylinders.

Several interesting facts are immediately apparent upon an inspection of this chart. The first observation is the very great superiority, as regards cavitation, of the bodies of revolution over the cylindrical bodies. This was to be expected from the fact that the velocities about bodies of revolution are much less than those about two-dimensional forms. The second somewhat surprising fact observed is that the

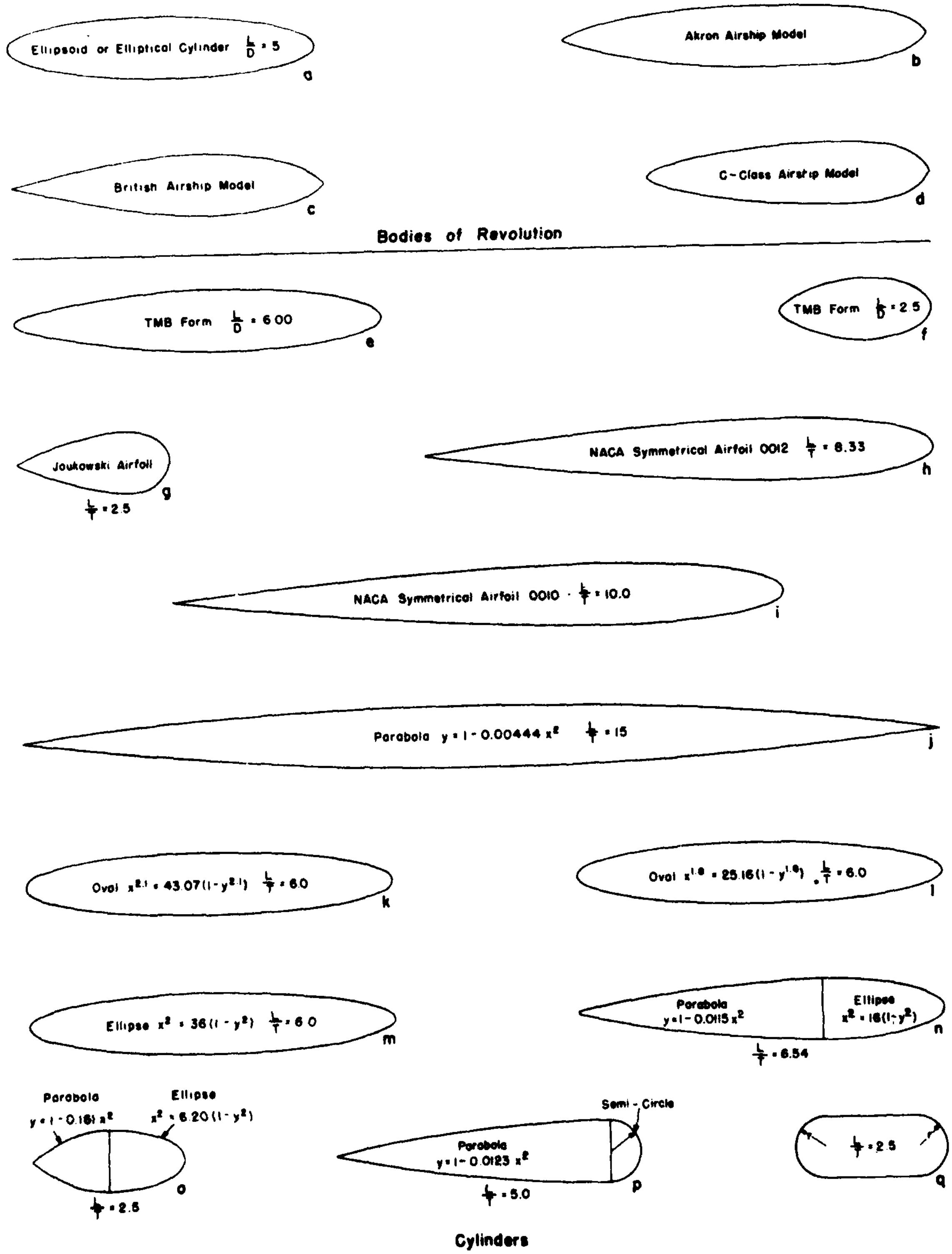


Figure 1 - Sections of Cylinders and Bodies of Revolution for which Cavitation Speeds were Calculated

elliptical shapes for both the three- and the two-dimensional forms are much superior to the corresponding types of more highly streamlined forms such as the airships and airfoils.

In Figure 3 are presented the cavitation speeds calculated for five oval sections of the type $x^n = c\ (1 - y^n)$.* It will be noted that when n is 2.0 this is the equation of an ellipse; when n is less than 2.0 the oval has a sharper nose than the ellipse and when n is greater than 2.0 the oval has a blunter form than the ellipse. The cavitation speeds presented in Figure 3 are plotted against the value of the exponent n and show a maximum for the value of 2.0. This indicates that the ellipse is the best oval shape, of this type, in regard to cavitation speed.

The reason for this may be seen by a comparison of the pressure diagrams of the ellipse and two adjacent ovals shown in Figure 4. The half sections of these bodies are also shown, plotted from the same origin of axes, for comparison. The pressure diagram of the narrow oval $x^{1.5} = 14.7\ (1 - y^{1.5})$ is typical of all of the ovals which have a narrower entrance than the ellipse, and shows a minimum pressure at the midpoint of the body, as does the ellipse, but has a greater negative pressure than the ellipse. The narrower the entrance, the greater the negative pressure. For bodies blunter than the ellipse, illustrated by the oval $x^{2.5} = 88.2\ (1 - y^{2.5})$, the minimum pressure no longer occurs at the midpoint of the body but shifts forward, and again the negative pressure becomes greater than that of the ellipse and increases with increasing bluntness.

The broken curve in Figure 2 gives the cavitation speeds for a family of TMB cylinders. The cross sections of these cylinders were selected to combine the advantages of the elliptical cylinder in deferring cavitation, and those of a streamlined form in deferring separation and reducing drag. This form was developed to make use of the high cavitating speed of the ellipse and the low resistance and reduced eddying flow characteristics of a streamlined form. Sections e and f, Figure 1, show the form of this body for two values of the length-thickness ratio, and the generalized coordinates are given in Table 1. The designs of the TMB model sound domes, the tests of which are presented in the following section, were all based on this form.

MODELS AND TEST APPARATUS

Nine models of sound-projector domes were tested in the 24-inch variable pressure water tunnel of the Taylor Model Basin to determine their speeds of cavitation. Five of the models, namely, WEA-1, WEA-1 Strut, JK-9, British, and RA78F208A, as shown in Figure 5, were tested at the request of the Naval Research Laboratory. Four other models, designed at the Taylor Model Basin and all based on the TMB form

* These equations, for fractional values of the exponent, may not be solved, except in the first quadrant, without the introduction of complex numbers. For the purposes of this report the ordinates were computed for the first quadrant only and these ordinates were then replotted in the other three quadrants assuming that the bodies were symmetrical about both the x and y axes.

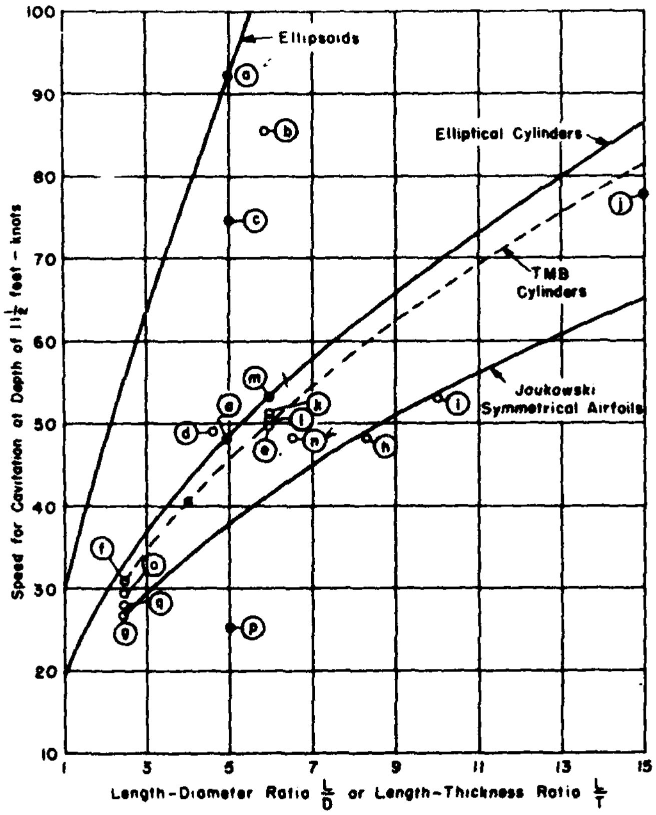


Figure 2 - Calculated Cavitation Speeds for Various Bodies of Revolution and Cylinders

The lower case letters in circles refer to the body shapes shown in Figure 1.

mentioned in the previous paragraph, were included in the tests. These are shown in Figure 5 and are designated as TMB-1, TMB-2, TMB-3, and TMB-4. The model TMB-1 has the same length and diameter as the British form and the same length-diameter ratio as JK-9. TMB-2 is a short strut section. TMB-3 has the same body as TMB-1 but has a supporting neck with higher length-thickness ratio than that model. TMB-4 has the same length and diameter as the Naval Research Laboratory Model RA78F208A. Table 2 presents in condensed form the general characteristics of all the forms.

The models were mounted in the water tunnel jet on a horizontal brass plate, to simulate the hull of a ship, as shown in Figure 6.

In testing a model the water speed was gradually raised while observing the model with an interrupted-light-type stroboscope. By use of the stroboscope the initial speed and location at which cavitation bubbles appeared could be accurately obtained. The speed was then further increased and the manner in which the cavitation progressed was noted. This was continued until all parts of the model showed heavy

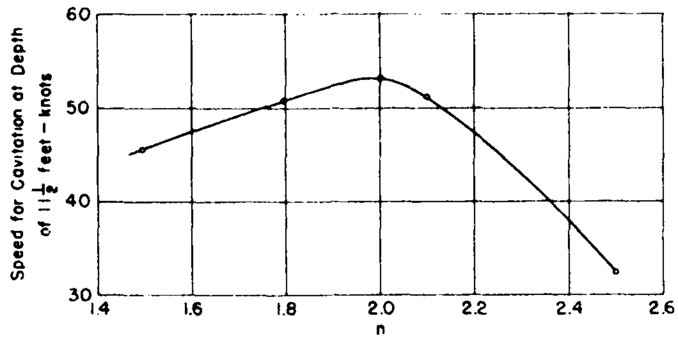


Figure 3 - Cavitation Speeds for Ovals of the Type $x^n = c(1 - y^n)$ for Length-Thickness Ratio of 6.0

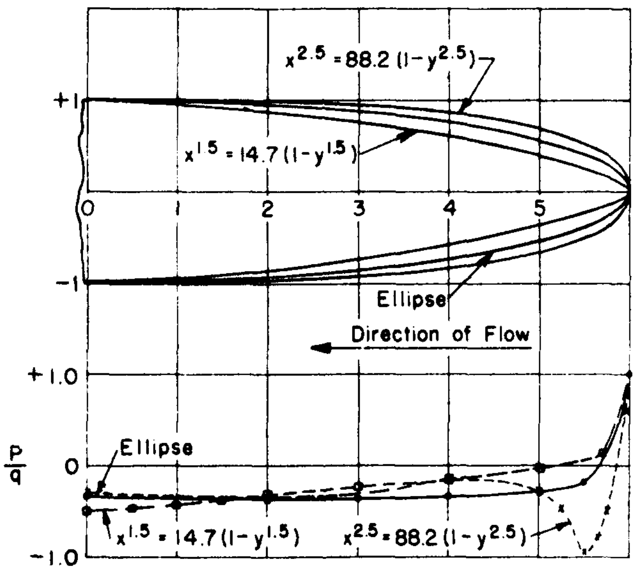


Figure 4 - Comparison of Pressure Distribution about Three Ovals for Length-Thickness Ratio of 6.0

cavitation. The initial cavitation speeds were checked for several values of total water pressure in the tunnel (submergence head plus equivalent atmospheric head on the free water surface). Photographs were taken of each model at various stages of cavitation.

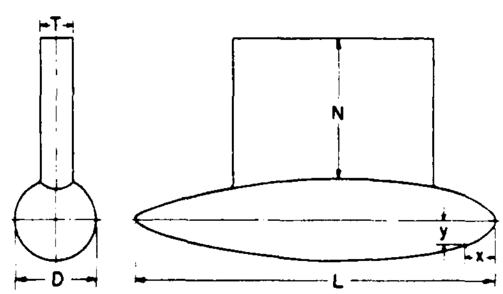
Corrections were applied to the speeds for the slight difference in head caused by the difference in vertical length of the supporting struts of the models.

The test results showed very little scale effect with the exception of Model RA78F208A which showed a slightly higher speed of cavitation with increasing Reynolds number. The Reynolds number of the tests ranged from 4.3×10^6, for the British dome, to 8.3×10^6, for the TMB-4. The speeds at which the tests were con-

TABLE 1

Offsets for TMB Struts and Bodies

$\frac{x}{L}$	$\frac{y}{D}$	$\frac{x}{L}$	$\frac{y}{D}$
0	0	0.800	0.3260
0.005	0.0756	0.850	0.2749
0.010	0.1064	0.900	0.2170
0.020	0.1498	0.930	0.1778
0.040	0.2092	0.950	0.1480
0.070	0.2717	0.970	0.1129
0.100	0.3186	0.990	0.0642
0.150	0.3774	1.000	0
0.200	0.4204		
0.250	0.4522		
0.300	0.4750		
0.350	0.4902		
0.400	0.4983		
0.450	0.4997		
0.500	0.4946		
0.550	0.4830		
0.600	0.4647		
0.650	0.4399		
0.700	0.4085		
0.750	0.3705		



L is the overall length and D is the maximum thickness or diameter.
For the bottoms of the struts use the value of y as radius at each station.
The nose radius is $0.5732\ D^2/L$, the tail radius $0.2027\ D^2/L$.
Volume of body of revolution - $V = 0.474\ LD^2$.
Center of gravity of body of revolution - $x = 0.461\ L$.
Area of section of a strut - $A = 0.746\ LD$.
Moment of inertia of area of section about longitudinal axis - $I = 0.04485\ LD^3$.
Section modulus - $I/C = 0.0897\ LD^2$.

ducted were high enough so that the effect of surface tension on the formation of cavities was probably negligible. In any event the results of the tests are an accurate indication of the relative resistance to cavitation of the various forms. There may be some uncertainty as to the quantitative accuracy of the full-scale speeds predicted.

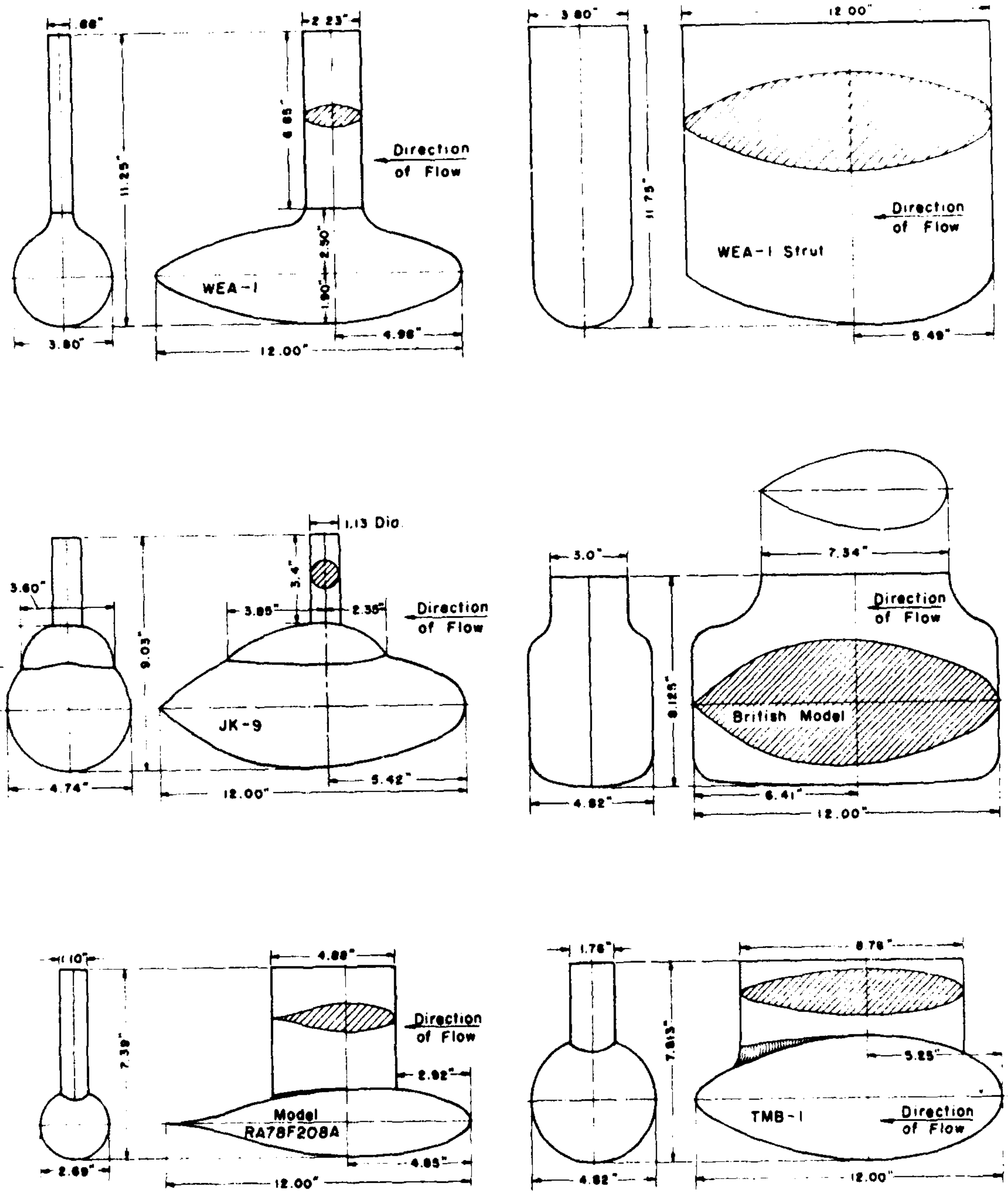


Figure 5 - Outline Drawings of Model Sound Domes

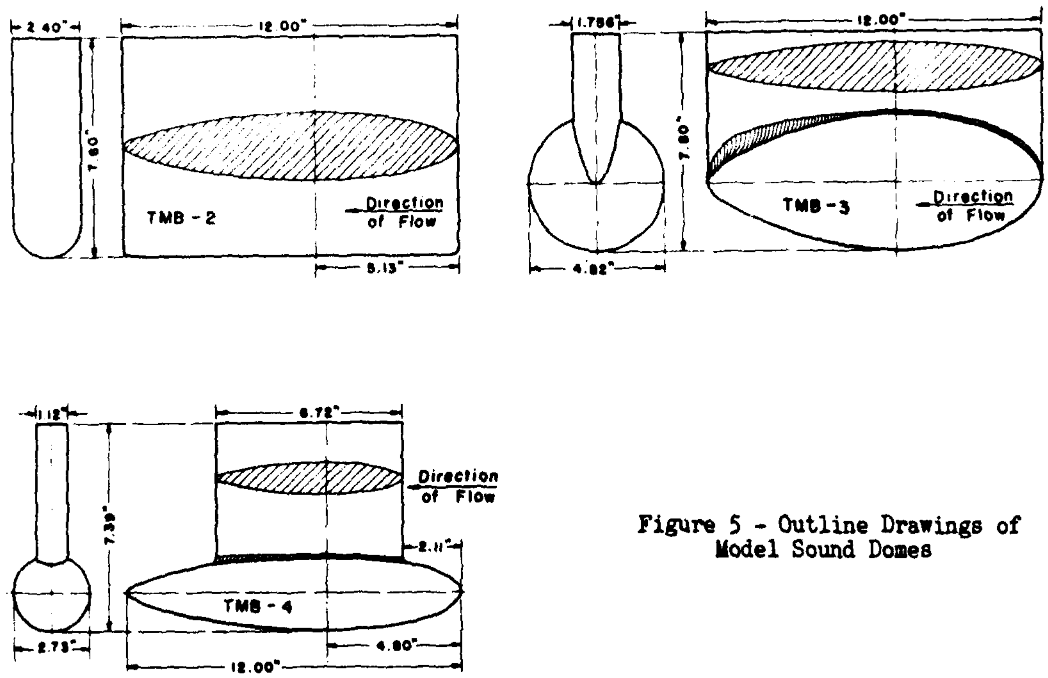


Figure 5 - Outline Drawings of Model Sound Domes

TEST RESULTS AND DISCUSSION

Photographs of the models for various stages of cavitation are presented in Figures 7 to 15 inclusive. The initial cavitation speeds for all the models are presented in Table 2 and are shown graphically in Figures 16 and 17, page 15. The bodies of the domes are compared in Figure 16 and the supporting struts, known as necks, are compared in Figure 17. The calculated curves for the ellipsoids, the elliptical cylinders, the TMB cylinders, and the Joukowski strut sections are included for comparison.

It should be noted that the calculations for the cylinders were based on the assumption of an infinite length, i.e., on a two-dimensional flow, and that the interference flow between the bodies and the struts was neglected, so that

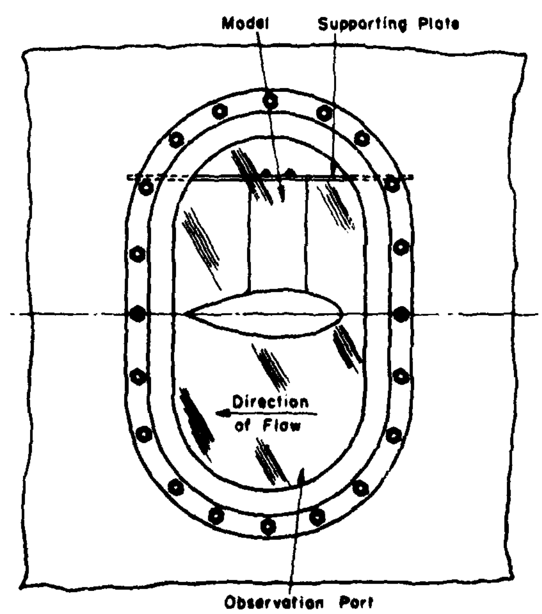


Figure 6 - Method of Mounting Model Sound Domes in the Water Tunnel

TABLE 2

Initial Cavitation Speeds and Various Physical Characteristics of the Model Sound-Projector Domes tested in the Variable Pressure Water Tunnel

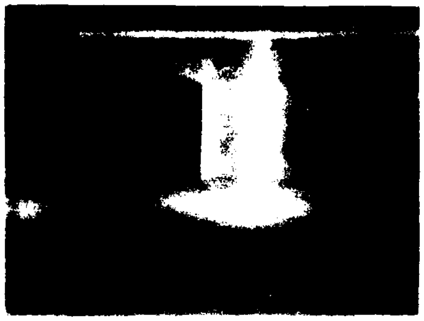
Designation	$\frac{L^*}{D}$ Body	$\frac{T^*}{D}$ Neck	$\frac{N^*}{D}$	Initial Cavitation Speed knots† Body	Initial Cavitation Speed knots† Neck	Model Scale
WEA-1	3.16	2.53	1.96	60.0	32.1	0.351
TMB-1	2.49	5.00	0.614	53.0	{38.5** 42.7	0.219
JK-9	2.53	1.00	0.905	43.5	21.0	0.283
British	2.49	2.45	0.612	38.5	29.0	0.219
RA78F208A	4.43	4.43	1.715	56.0	39.8	0.279
TMB-3	2.49	6.83	0.614	51.4	{43.7** 51.4	0.219
TMB-4	4.43	6.00	1.715	75.0	48.7	0.279
WEA-1 Strut	3.18	-	-	-	39.1	0.392
TMB-2 Strut	5.00	-	-	-	53.4	0.249

* See the diagram with Table 1.

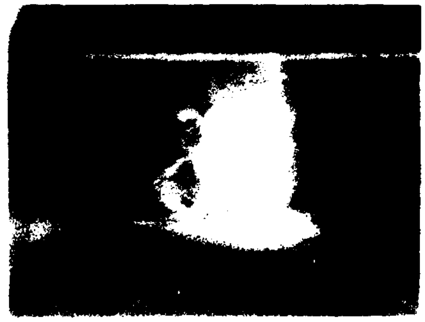
** Inception of cavitation first appeared at the junction of body and neck several knots below the speed at which the neck itself started cavitating.

† The speeds given here and in the photographs following are full-scale ship speeds.

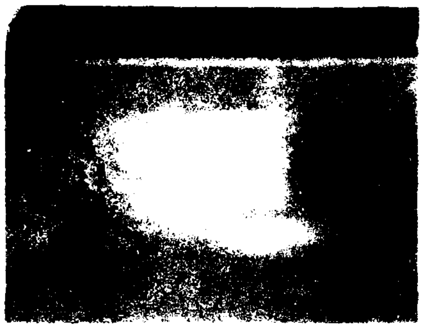
exact agreement between the calculated and observed results cannot be expected. The close agreement shown on Figure 17 between the calculated and the observed speeds of cavitation for the circular cylinder of the neck of the JK-9 model and the elliptical neck of the WEA-1 model, for example, simply indicates that the body interference is sufficient to offset the finite vertical lengths of these struts. More severe cases of body interference are shown by the photographs of the initial cavitation about the models TMB-1 and TMB-3, on Figures 13 and 14, page 14. The initial cavitation occurs at the junction of the neck and the body on these models, at speeds several knots below that at which cavitation begins on the necks proper. This is because of the extremely short vertical distance, 0.63 body diameters, between the plate simulating the hull of the ship, and the short, full body of this dome. A comparison of the neck length of these models with those of Models JK-9, and WEA-1, whose neck lengths are 90 per cent and 196 per cent of the body diameters respectively, and which showed no interference of this type, indicates that the minimum vertical neck length of models of this type should be about one diameter of the body.



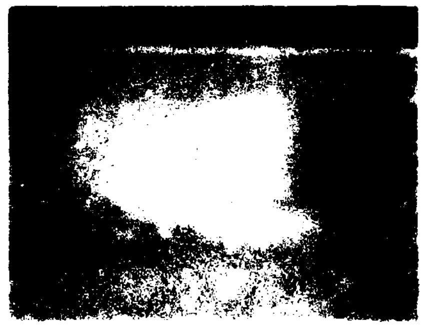
Initial Cavitation on Neck at 39.6 knots



Moderate Cavitation on Neck at 50.3 knots



Initial Cavitation on Body at 60.4 knots



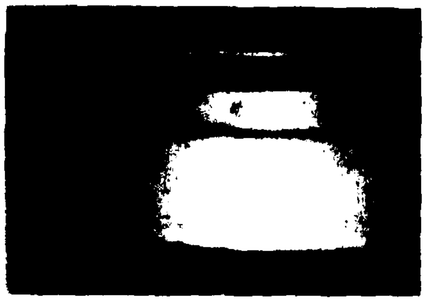
Heavy Cavitation on Neck and Body at 68.7 knots

Figure 7 - Various Stages of Cavitation on Sound Dome Model RA78F208A

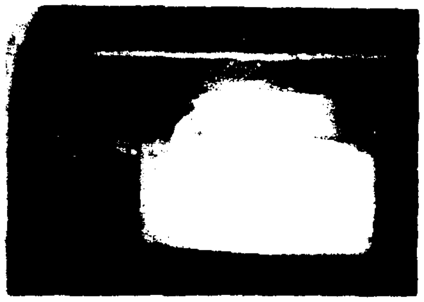
In general the length-thickness ratio for the supporting struts is required to be much greater than the length-diameter ratio of the body for the same initial cavitation speed. Models WEA-1 and JK-9 are good examples of the case in which a good body form has been spoiled by using a poor choice of supporting strut. The WEA-1 body showed no cavitation until it reached the high speed of 60 knots, but it was supported by a strut of low fineness ratio which started cavitating at only 32 knots. Similarly the body of Model JK-9 started cavitating at 43 knots while the cylindrical neck cavitated at the low speed of 21 knots.

The importance of the length-thickness ratio of the neck is again shown by a comparison of the initial cavitation speeds of the TMB-1 and TMB-3 models. The bodies of these domes are identical; the only difference between them is the length-thickness ratios of the supporting struts, 5.0 for TMB-1 and 6.8 for TMB-3. The initial speed for cavitation was raised from 38.5 knots for the TMB-1, to 43.7 knots for the TMB-3.

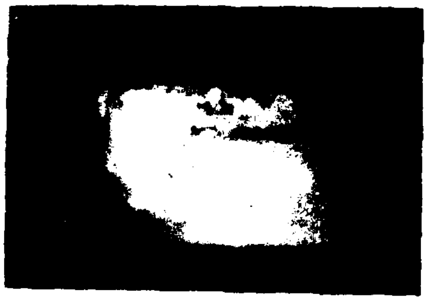
The effect of the shape of the body may be observed by comparing the cavitation speeds of the bodies of the three Models TMB-1, JK-9, and the British model,



Initial Cavitation on Neck at 29.2 knots

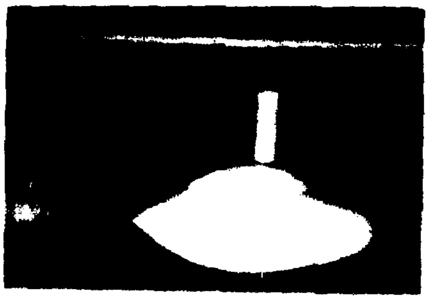


Initial Cavitation on Body at 38.8 knots

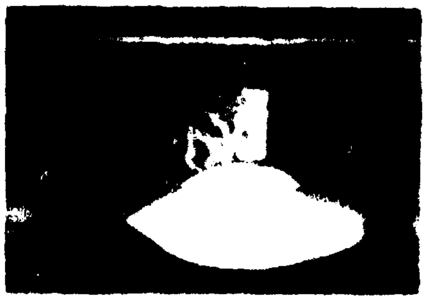


Heavy Cavitation on Neck, Moderate on Body at 49.1 knots

Figure 8 - Various Stages of Cavitation of British Sound Dome Model



Initial Cavitation on Neck at 21.0 knots



Moderate Cavitation on Neck at 27.5 knots

Initial Cavitation on Body at 44.8 knots

Figure 9 - Various Stages of Cavitation on Sound Dome Model JK-9

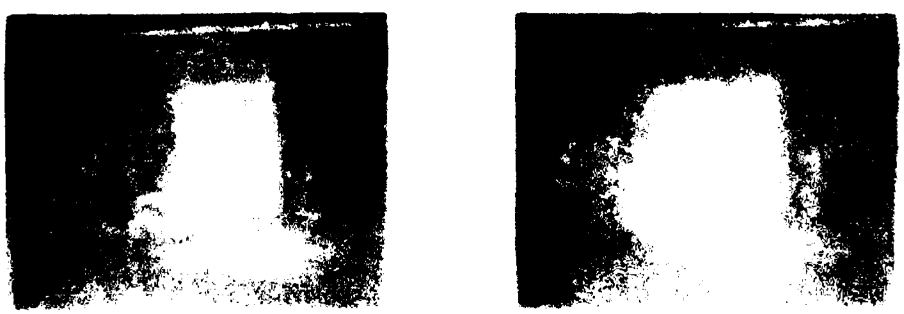
Initial Cavitation at 39.1 knots Moderate Cavitation at 43.8 knots

Figure 10 - Various Stages cf Cavitation on Strut Model WEA-1

Initial Cavitation at 53.4 knots Heavy Cavitation at 66.4 knots

Figure 11 - Various Stages of Cavitation on Strut Model TMB-2

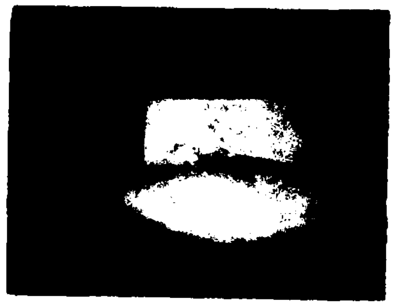
Initial Cavitation on Neck at 32.4 knots Light Cavitation on Neck at 38.5 knots



Heavy Cavitation on Neck at 50.4 knots Initial Cavitation on Body at 60.2 knots

Figure 12 - Various Stages of Cavitation on Sound Dome Model WEA-1

Initial Cavitation at Junction of Neck and Body at 38.5 knots

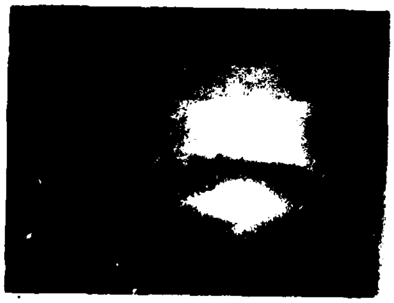


Initial Cavitation on Neck Proper at 42.6 knots

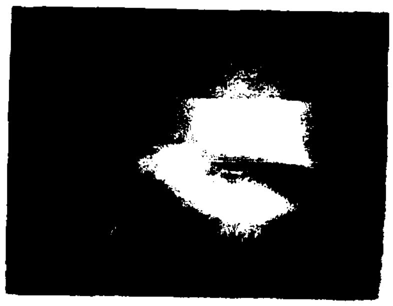
Initial Cavitation on Body at 52.6 knots

Heavy Cavitation on Body and Neck at 60.1 knots

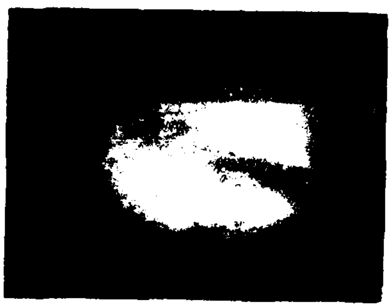
Figure 13 - Various Stages of Cavitation on Sound Dome Model TMB-1



Initial Cavitation at Junction of Neck and Body at 44.2 knots

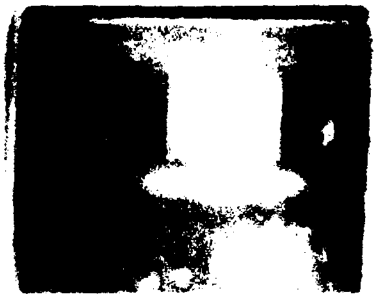


Initial Cavitation on Neck Proper and on Body at 51.4 knots



Heavy Cavitation on Neck and Body at 63.6 knots

Figure 14 - Various Stages of Cavitation on the Sound Dome Model TMB-3



Initial Cavitation on Neck at 48.7 knots

Heavy Cavitation on Neck at 69.8 knots

Figure 15 - Various Stages of Cavitation on Sound Dome Model TMB-4

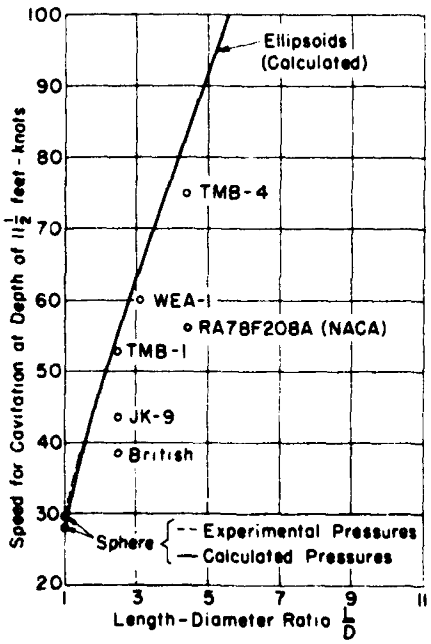


Figure 16 - Comparison of Cavitation Speeds of Sound Domes

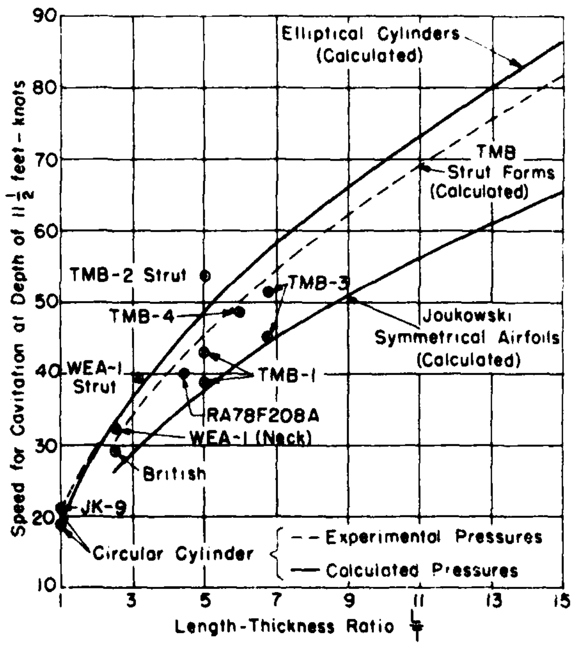


Figure 17 - Comparison of Cavitation Speeds of Necks of Sound Domes and of the Strut Model Sound Domes

as indicated on Figure 16. These all have approximately the same length-diameter ratio so that any differences in the cavitation speeds may be attributed to differences in shape. The initial cavitation speed of the TMB-1 model was 52.5 knots, slightly below the curve for the ellipsoids; the JK-9 model cavitated at 43.5 knots, and the British form at 38.5 knots, 14 knots below that of TMB-1 model. The effect of shape is shown further by comparison between Models TMB-4 and RA78F208A, which also have the same length-diameter ratio for the bodies and necks.

The relatively poor showing of the RA78F208A model is probably caused by the inflection in the curve of its cross section and its extremely fine shape at the stern. This shape is somewhat impractical because of the danger of damage to the long, thin after portion in handling.

The cavitation speeds of the WEA-1 and TMB-2 strut models are given in Table 2 and are plotted in Figure 17 on the same chart with the results for the necks of the other sound domes. The speeds for both lie above the curve calculated for the elliptic cylinders. The reason for this is that the vertical length of the struts is so small that the flow about them is not two-dimensional as it was assumed to be for the calculations but approaches that of a body of revolution.

In general the test results confirm the prediction of the calculations that the TMB forms, for the same length-diameter or length-thickness ratio, will give higher speeds of cavitation than the other models tested.

The data presented in Figures 16 and 17 show that the old spherical sound-projector dome and the British dome are not cavitating at the limiting service speeds of these bodies. The curve for the ellipsoids, Figure 16, for length-diameter ratio $L/D = 1.0$, shows that the sphere should not cavitate until it reaches a speed of 29 knots, and the curve for elliptical cylinders, $L/T = 1.0$, Figure 17, shows that cav-

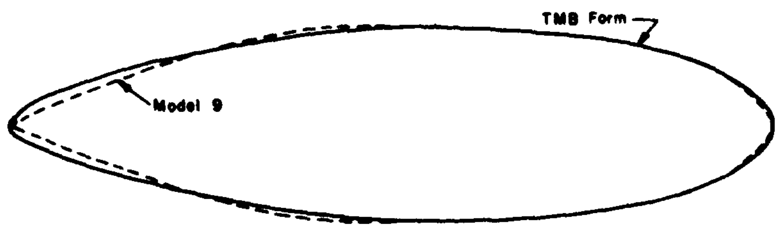


Figure 18 - Comparison of TMB Form with that of Model 9
Reference (5) for Length-Thickness Ratio of 4.0

itation should not occur on the cylindrical neck at speeds less than 21 knots. In full-scale trials, however, this dome became inoperative at speeds of only 16 to 18 knots. Similarly the present tests of the British model showed that the body did not cavitate under 42 knots and the neck under 29 knots while in the full-scale trials this dome became too noisy to use above 20 to 24 knots. The cause of the failure of these domes then appears to be something other than the cavitation noise. It is probable that the origin of the noise causing the failure of these domes is the violent eddying of the flow that is known to exist about bodies of low length-diameter ratio.

Reference (5) presents the results of the tests of 12 strut forms conducted in the NACA high-speed basin at the request of the Taylor Model Basin. Three of these, Models 7, 8, and 9, were very similar to the TMB forms. Model 9 is compared to the TMB form of the same length-diameter ratio in Figure 18. The forepart of the strut is almost identical but the tail of Model 9 comes to a point instead of being rounded as in the case of the TMB model. The test results as presented in Figure 21 of Reference (5) indicate that Models 7, 8, and 9 give the highest cavitation speeds of all those tested. This agrees with what might be expected from the calculated results presented in Figure 2 of the present report.

OBSERVATION OF SEPARATION OF FLOW

Observations of the flow about the sterns of two of the models, TMB-1 and the British model, were made by gluing streamers of linen thread to the sides of the afterbodies at intervals of one inch; these streamers were free to "weather-vane" about the end glued to the surface. They indicated the region of separation or the inception of eddying flow by a violent whipping about and by reversing their direction in the region of well developed eddies.

The inception of separation on the British model occurred about four inches from the stern while that on the TMB-1 occurred at 1 1/2 inch from the stern, Figure 19. A comparison of the areas of cross section of the two models at these two points shows that the area of disturbance on the British model is 7.4 times that of TMB-1 and the distance of the inception of separation from the location of the sound projector would be approximately 1.8 times as great for TMB-1 as for the British form.

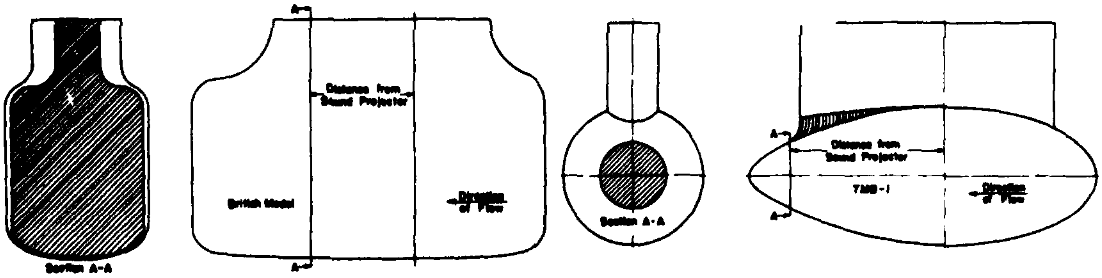


Figure 19 - Comparison of Areas of Section at Separation Point of Two Sound Projector Domes

Separation is estimated to occur at the Sections A-A on the two forms.

If it is assumed that the intensity of the eddying noise varies directly as the area of the disturbance and inversely as the square of its distance from the sound receiver, then the TMB-1 dome would have only about 1/24 of the eddying noise of the British form.

CONCLUSIONS

1. One of the most interesting and most important findings of the theoretical investigation is the fact that the elliptical shape for either a two- or a three-dimensional body has the highest cavitating speed of all the shapes investigated.

2. The calculations of the cavitation speeds and the test results presented in this report indicate that cavitation noises may be completely eliminated about a sound dome, within the speed range of the fastest vessels, by the proper choice of form and length-diameter ratio of the body. In general the length-diameter ratio of a body of revolution should be not less than 3.5, and that of a cylinder or strut should be not less than 4.0. Shorter bodies than these will give excessive resistance and greater noise because of the separation of flow and the resulting eddying motion about the stern of the body.

3. The TMB forms will cavitate at higher speeds than the conventional streamlined forms and will have considerably less resistance and less eddying noise than the elliptical forms.

4. Some existing sound domes become inoperative before cavitation speeds are reached, which indicates that the noise resulting in the failure of the domes has some origin other than cavitation. The origin of these noises is probably in the violent eddying flow on the after portion of these bodies which have low length-diameter ratios. Further research on large-scale domes, in which sound measurements are to be made, is in progress.

5. The data presented herein should be useful in the general design of struts wherever it is desired to avoid cavitation.

REFERENCES

(1) "Noise from Two-Bladed Propellers," by E.Z. Stowell and A.F. Deming, NACA Report 526, 1935.

(2) "Flow about a Pair of Adjacent, Parallel Cylinders Normal to a Stream, Theoretical Analysis," TMB Report 485, July 1942.

(3) "Flow and Drag Formulas for Simple Quadrics," by A.F. Zahm, NACA Report 253, 1927.

(4) "General Potential Theory of Arbitrary Wing Sections," by T. Theodorsen and I.E. Garrick, NACA Report 452, 1933.

(5) "Tank Tests of Ship-Propeller Strut Sections," by James M. Benson, Norman S. Land, and Robert F. Havens. CONFIDENTIAL NACA Memorandum Report for Bureau of Ships, Navy Department, 16 April 1942.